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Multiple openings of forward markets: Experimental evidence[1]

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Abstract:

We test the strategic motive to sell forward in experimental Cournot duopoly and quadropoly environments with multiple forward markets. Using random matching, we test two versions of forward markets with finite (Allaz and Vila, 1993) and indefinite number of periods. We find that the results for the Allaz and Vila (1993) model are remarkably close to the predicted theoretical results for both duopolies and quadropolies. We then test a version of the model to allow for indefinitely many periods. There are multiple equilibria in this theoretical model, including both the competitive and collusive outcomes. We find that the initial "collusive hypothesis" is not ratified, and that outcomes are nearly competitive. Sales take place mostly in the first few openings of futures markets. Again, these results hold for both duopolies and quadropolies.

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1. Introduction

Does the strategic motive in using forward markets enhance competition? The little experimental (Le Coq and Orzen (2006) and Brandts *et al*. (2008)) and empirical literature (Wolak, 2000) agrees with this assertion. Theory, however, is not clear on the issue. Allaz (1992) and Allaz and Vila (1993) suggest pro-competitive outcomes while Ferreira (2003), Mahenc and Salanie[2] (2004) and Liski and Montero (2005) suggest anticompetitive outcomes[3].

The experimental evidence points towards the fact that forward markets are competitive (Le Coq and Orzen, 2006 and Brandts *et al.*, 2008). Le Coq and Orzen motivate their study based on Allaz and Vila (1993). In their experiments they have a single forward and a spot market phase. They show that, relative to the spot market, the introduction of forward markets does have competition enhancing effects. As predicted by theory subjects avail of the forward markets. Forward markets are not as competitive as theory predicts when there are two firms, but are not significantly different than the theory prediction for four players.

The second experimental study (Brandts *et al* is based on a specific design of forward markets in the electric power industry. They consider both quantity and supply functions as strategic variables. In a model following Allaz and Vila, they find that, indeed, subjects show a pro-competitive effect, and that they sell more if the model has a forward market compared with the situation in which this market is not available. Studying the effects of forward markets when 2 or 3 firms can submit quantities or supply functions, they find that the introduction of forward markets has competition enhancing effects. Moreover, supply functions have efficiency enhancing effects in the presence of forward markets.

The empirical research on forward markets is scarce. For the Australian power market, Wolak (2000) shows that the effect is pro-competitive when firms use forward markets. One should, however, add a note of caution. Even though the use of forward markets is spreading, in many instances market regulation requires firms to participate in these markets. Most models described above agree that, when used, forward markets

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[2] They study forward markets with price competition and differentiated goods.

[3] Other papers have explored aspects of the competition that may affect the strategic behavior of the forward markets. For example, Hughes and Kao (1997) and Ferreira (2006) study the observability of actions, Murphy and Smeers (2005) study capacity choice, Gans, Price and Woods (1998) and Newbery (1998) study entry, while Bushnell *et al.*(2008) study regulatory arrangements to promote forward contracting.

are pro-competitive. However, there is still the question whether firms will avoid competition by not using them when deciding in a non-regulated market.

In this paper we experimentally test the strategic motive to sell forward in experimental oligopolies[4] in a random matching framework. We run our experiments with two and four firms, and with two different treatments for the use of forward markets. In a first treatment both the duopoly and quadropoly participate in two forward markets prior to the spot phase. This implementation directly tests the model of Allaz and Vila (1993) where the number of forward periods is (exogenously) fixed[5]. According to the theoretical results in Allaz and Vila, the number of forward market periods plays a substantial role in the prediction in two specific ways. First, the total quantities are affected, increasing with the number of periods. Second, the way the quantities are divided among the different forward and spot markets must follow a precise path.

Le Coq and Orzen (2006) report similar qualitative results for the model with only one (period of) forward market and fixed matching. For duopolies, they report results where total quantities tend to be substantially less competitive than the theoretical prediction. Further, they observe lower quantities in the forward market. Spot markets, meanwhile, observe greater quantities compared to the theory prediction. Quadropolies, on the other hand sell more and a greater proportion of quantity is sold in the forward market.

Our implementation (with two forward markets) is a closer test of the one shot Allaz and Vila (1993) model due to the random matching setup[6]. We observe support for the theory in two aspects. First, average output, for both duopolies and quadropolies, is very close to the theoretical prediction. Second, and even more remarkably, outputs are observed following the predicted proportional shares among the different forward and spot markets. In this sense our experiments support the competition enhancing effect of forward markets and support the predictions of Allaz and Vila (1993).

Given the first experimental results by Le Coq and Orzen (2006) and Brands *et al*. (2008), we wanted to further test the effect of increasing the number of periods on competition. To achieve this we setup a market where an endogenous rule closes the market. In our implementation, the number of forward market periods comes to an end

[4] Note that Brandts *et al.* test the role of forward markets in a design specifically motivated by the electric industry.
[5] Le-Coq and Orzen (2006) study the exogenous close rule with just one forward market.
[6] We discuss the differences between our design and Le-Coq and Orzen (2006) in detail later.

whenever all subjects decide not to use them anymore. When this occurs, i.e. when no positions are taken in the forward market, the spot market follows next. Our design is a compromise between the model in Ferreira (2003) where there are infinitely many moments to sell forward, and the model of Allaz and Vila with a big, but finite number of forward market periods. This is so because no one of the two alternatives can be implemented exactly in an experiment.

On the one hand, the experimental design cannot accommodate infinitely many periods or the potentially infinite division of quantities, both necessary for the model in Ferreira (2003), so that any experimental attempt becomes closer to the case of Allaz and Vila (1993) with many openings of futures markets.

On the other hand, the experimental design with a potentially infinite number of forward openings has the drawback of having to exogenously decide the price at which the forward sales should be traded. As the demand is automated, we have to make a choice in the equilibrium we want to test. To test for the competitive equilibrium requires setting a price equal to marginal cost for all forward sales. But this implies that subjects have no use for the forward markets, and the experiment becomes just a Cournot experiment. Thus, the only meaningful hypotheses are the ones that depart from the competitive behavior. We decided to test the collusive equilibrium and, accordingly, set the price in forward markets equal to the Cournot price in the residual demand, as “collusion” in Ferreira (2003) means that players tacitly agree to avoid the use of forward markets and compete only in the spot market.

Our experimental results reject that hypothesis and show that subjects choose total quantities at the competitive levels, and also that the quantity is mainly sold in the first openings of the forward market, leaving almost nothing to sell in the rest of the markets, including the spot market. Because large quantities are sold in the first openings of the forward markets, the corresponding Cournot price in the residual demand is small, and converges to the competitive price. In this sense, the experimental results converge to the competitive hypothesis.

The paper is structured as follows. In Section 2 we present the theoretical motivation behind the experiments. In Section 3 we present the experimental design. This is followed by the results in Section 4 and, with more detail, in Section 5. Section 6 concludes.

2. Theory

Below we outline the theoretical models that motivate our experimental design. We focus on Allaz (1992), Allaz and Vila (1993) and Ferreira (2003). In a Cournot duopoly, Allaz (1992) shows that, if firms can sell in a forward market previous to the spot market, the strategic interactions result in a more competitive outcome. In a later paper, Allaz and Vila (1993) show that this pro-competitive effect increases as the forward markets open more often.

Ferreira (2003), on the other hand, shows that if the forward market has infinitely many moments in which trade is allowed, any price between Cournot and perfect competition can be sustained in equilibrium. Next, we outline two versions of forward markets. In the first version (Allaz and Vila, 1993) the number of forward markets is exogenously determined. In the second version the forward markets can open many times, with an endogenously given stopping rule.

2.1 Allaz and Vila (1993)

Suppose there are *n* firms in an oligopolistic market that compete in quantity and face a linear demand $p = A - q$ with zero costs. If, previous to this spot market, firms can sell forward, standard Cournot analysis shows that, in equilibrium, Firm *i* will sell $s_i = \frac{A-F}{n+1}$ in this spot market, where *F* is the total of quantities sold in the forward market. The equilibrium price is $p_s = \frac{A-F}{n+1}$.

If there are 2 periods of forward markets, in period $t = 2$ Firm *i* will solve the problem

$$\max_{f_i^2} (f_i^2 + s_i) p_s ,$$

where $s_i = \frac{A-F}{n+1}$, and $p_s = \frac{A-F}{n+1}$.

Taking into account that now $F = \sum_{j=1}^{n} f_j^1 + \sum_{j=1}^{n} f_j^2$, with f_j^t as the quantity sold by Firm *j* in the forward market at time *t*.

We assume a no-arbitrage condition in solving this problem. This implies that forward and spot prices are equal. For example, Allaz (1992) shows that the introduction of arbitrageurs that buy in the forward markets to sell in the spot implies that there is no arbitrage in equilibrium. Substituting the arbitrageurs with the no-arbitrage condition gives the same results and simplifies the model. The solution of the problem for each firm gives the solution

$$f_i^2 = \frac{n-1}{n^2+1}(A - F^1), \text{ and } s_i = p_s = \frac{1}{n^2+1}(A - F^1),$$

where $F^1 = \sum_{j=1}^{n} f_j^1$.

Now, in period 1 of the forward market, Firm i solves

$$\max_{f_i^1} (f_i^1 + f_i^2 + s_i) p_s,$$

where $f_i^2 = \frac{n-1}{n^2+1}(A - F^1)$, and $s_i = p_s = \frac{1}{n^2+1}(A - F^1)$.

The solution of this problem for all firms gives

$$f_i^1 = \frac{(n-1)^2 A}{n^3 - n^2 + n + 1}.$$

The rest of the variables are found substituting this value in their corresponding expressions. When firms face identical, constant marginal costs *c*, $A - c$ replaces *A* in all of the above expressions, and the price will be given by the expression, $p_s + c = \frac{1}{n^2+1}(A - c - F^1)$.

2.2 Extensions of Allaz and Vila (1993)

Allaz and Vila examine a model with finitely many periods of forward markets and find that, as the total number of periods increases, the total sold quantity also does. Further, as the number of periods of forward markets goes to infinite, the limit of the quantity is the competitive outcome. For the particular case of two firms, the case of *T* periods in which the forward market is open, gives

$$p = s_i = f_i^t = \frac{A}{3+2T}, \text{ and } q = 2\frac{(1+T)A}{3+2T}.$$

It can easily be checked that, as *T* increases, the price *p* goes to zero, and total quantity *q* converges to *A*, the competitive outcome.

However, the limit of the equilibria in finite games may not exhaust all the equilibria in the infinite game. In fact, something similar to a Folk Theorem is obtained if the infinite case is analyzed directly, in which all total quantities (and their corresponding market prices) between competitive and Cournot can be observed in equilibrium. This result is shown in Ferreira (2003). The Cournot result can be supported in equilibrium by the following strategy. Firms sell nothing in the forward markets and play standard Cournot in the spot market. If a firm deviates and sells forward at some point, the other firms also sell in the next period. When one firm sells forward, it makes some extra profits with respect to the equilibrium behavior. However, when the other firms also sell in the next period to punish the deviation, its profits are reduced. The punishment phase is calibrated so the deviator makes a net loss. Ferreira shows that similar strategies can actually support any outcome between the competitive and the Cournot quantities. However, the Cournot outcome is the only one that satisfies some equilibrium refinements like renegotiation-proofness or Pareto perfection.

Notice that after firms sell in the forward market, each of the subgames is a reduced version of the original game (with a smaller residual demand, depending on how much was sold in the previous markets). This makes the model different from a repeated game, because, in the repeated game, the demand remains the same in each period. There is, however, a similar result once it is established that there is still room for credible punishments in spite of the smaller demand and of the smaller impact of the punishment.

3. Experimental design

Subjects were recruited from the undergraduate student populations at George Mason and Chapman Universities. They were told that the experiments would last around two hours[7]. Table 1 summarizes experimental details.

A total of 20 duopoly and 9 quadropoly experiments were run with 76 subjects. Including the instructions, the experiments finished in two hours (see Appendix for instructions). At the end of the instructions subjects were required to play practice rounds against a computer before taking part in the experiment.

	Table 1: Experiments			
	Exogenous Stop		Endogenous Stop	
	George Mason	Chapman	George Mason	Chapman
Duopoly	3	6	4	6
Quadropoly	4	-	5	-

[7] The number of experiments ran depended on subject show-up.

The market demand used in all the experiments is $P = 105 - Q$, and the constant marginal cost for all firms was set equal to 15. In the exogenous close treatment, there were 2 periods of forward markets previous to the spot market, while in the endogenous close treatment, the forward market opens again in period t if positions in $t-1$ were different from zero.

To deal with the no-arbitrage condition, the forward market price in each of the forward markets periods is computed as the theoretical price that would prevail in the remaining periods if the theoretical model is solved with the residual demand. For example, let the total of sales in the first period of forward markets be 20. In the exogenous close treatment, the program then computes a forward market price for that period as the equilibrium price (as in Allaz and Vila) with one period of forward markets and demand given by $p = A - 20 - q$. This way we can test the hypothesis whether subjects behave as in the Allaz and Vila model.

In the endogenous close case, we had, in principle, multiple choices for hypothesis testing. If subjects interpret the world as in Ferreira (2003), there would multiple equilibria, and no clear theoretical prediction could be obtained[8]. If, on the other hand, subjects interpret the world as in Allaz and Vila with many periods, the theoretical prediction would be one with prices equal marginal costs for *all* futures markets. However, setting a competitive price would render forward markets unattractive, as they would offer no profits. In that case, one would expect subjects to take no positions in the forward markets and wait till the spot Cournot market. In view of this, we found it more interesting to test a different hypothesis, namely whether subjects, in a repeated situation were forward market are attractive, refrain from using the forward markets to avoid its prisoners' dilemma trap. This would give higher profits by using the spot market alone, as in the best equilibrium in Ferreira (2003). To that end, we set the price equal to the Cournot equilibrium in the residual demand.

Subjects could see own and others' output, price, and costs of the rivals for any past period. Rival identity is unknown in all the experiments and subjects were randomly re-matched after each period. Subjects are explained the process of price determination in the instructions, and given specific examples. They are provided with a calculator showing two output choices, "mine" and "others", and subsequent own

[8] The experimental evidence suggests that subjects may cooperate in finite games with a repeated structure (centipede games, repeated prisoners' dilemmas, etc.) if the game is long enough (see Dal Bó, 2005).

profits. By resetting own and others' output they can estimate how their profits vary as either one of the two output changes.

Le Coq and Orzen (2006) were the first to directly test Allaz and Vila's model in the laboratory. In their design matching were fixed and the experiments ran for 30 periods. Our experimental design, however, has several features that are different from theirs. First, subjects are randomly matched in each round of our experiments. In this sense our experiments are a true test of the one shot prediction in Alaz and Vila. Subjects in our experiments can be matched against the same partner with a positive probability. However, subjects do not observe rival identity which makes collusion and other group behavior very difficult. Given that random matching oligopoly experiments give more competitive outcomes (Huck *et al.*, 2004) our design favors competitive outcomes. Further, note that although theoretically the finite repetition of the game with only one equilibrium cannot generate cooperation, there is experimental evidence that subjects may still cooperate for some rounds if the game is long enough (Dal Bó, 2005).

Second, we run our experiments for nearly seventy rounds (Le Coq and Orzen ran theirs for 30 periods). We do this to facilitate subject learning as forward markets are complicated mechanisms.

Third, for the exogenous close, we use two periods of forward markets. Two periods of forward markets make the market much more competitive than just one period, especially for the quadropoly case. This, together with the random matching, made the experimental setting closer to the theoretical conditions.

Fourth, to observe behavior under several forward market periods and to check the hypothesis whether an increased number of forward markets facilitates collusion, we test the endogenous close treatment.

Finally, we should mention that all statistical tests for differences in means are done using the standard t-test. In tests for market quantities, each market (two or four firms, depending on the treatment) each period (a round of several futures and one spot market) is considered an observation. In tests for individual quantities, each individual choice each round is considered an observation.

4. A brief look at experimental results

4.1 Exogenous Close

It will be useful to look at some summary statistics before we look at detailed results. Table 2 (f denotes the number of forward markets) compares the theoretical and average values in the experiments for both the 2 and 4-firm case and for both inexperienced and experienced subjects. For completeness, it also shows the average quantities in Le Coq and Orzen (2006). For simplicity of exposition all quantities are expressed relative to the competitive amount (set to 100).

Table 2: Summary Statistics (% of competitive quantity)
Exogenous Close

	Cournot (Monop.)	Allaz and Vila Theory $f=1$	**Le Coq and Orzen Experiments** $f=1$	Allaz and Vila Theory $f=2$	**Our Experiments** $f=2$
2 firms	66.66 (50)	80	**75.04**	85.71	**85.56**
4 firms	80 (50)	94.1	**100.74**	98.11	**99.85**

The first result that stands out in Table 2 is that the average behaviour of subjects is in line with theory. While the average output observed for duopoly is near the prediction of the AV model, a quadropoly gives near competitive outcomes.

Comparing our summary results with Le Coq and Orzen one sees that, in their experiments, and relative to the theory, the duopoly output is marginally significantly lower while, quadropoly output is significantly higher[9]. Output produced by a quadropoly is above the competitive level of output. This could be due to the fact that they had zero marginal costs. The presence of zero marginal costs, however, does not seem to matter for a duopoly.

Relative to their results, ours are more in line with theory. Average output produced by both duopoly and quadropoly is remarkably close to the equilibrium prediction.

[9] They report p-values of 0.065 and 0.042, respectively (p. 421).

4.2 Endogenous close

Table 3 compares the theoretical and the average values in the experiments. As before, in order to make comparisons easier, we normalize all quantities as percentages of the competitive quantity.

Table 3: Summary Statistics (% of competitive quantity) Endogenous Close			
	Competition	Cournot	**Our experiments**
2 firms	100	66.66	**98.32**
4 firms	100	80	**103.23**

We see that subjects behave even more competitively than in the case of two periods of futures markets, which goes against the hypothesis that subjects can find a way to revert to the Cournot equilibrium by avoiding the use of the forward markets. We examine this with more detail next.

5. A closer look at the data

5.1 Exogenous close: Duopoly

Looking at summary data we know that subjects behave according to theory. Analyzing how individuals make use of the forward and spot markets, we see that overall output is remarkably close to the theory prediction. Note, however, that the quantities chosen in forward markets are significantly different from the theoretical prediction.

Table 4 compares theoretical predictions for the forward and spot markets against the observed quantities, and the theoretical quantity (given the production in the previous period). The theoretical prediction lists the subgame perfect equilibrium quantities in each stage. The theoretical predictions for the residual demand are computed as the subgame perfect equilibrium quantities in the subgame.

Thus, given the average of 35.68 units in the first forward stage, the rest of the game is that of a one-period forward market (as in Allaz and Vila) with demand $p = 100 - 35.68 - q$. The theoretical prediction for the second period of forward markets in this sub-game is 25.73. Given the residual demand and the average production in the two forward markets, the theoretical prediction in the spot market is the Cournot equilibrium in the duopoly game with demand $p = 100 - 35.68 - 22.3 - q$.

We also compare subject behavior with the theoretical quantities in the residual demand (given observed quantities). We do this because, if we do not, we may regard as non-equilibrium behavior a choice that is indeed equilibrium behaviour, if we consider the appropriate subgame.

Table 4: Exogenous Close, Duopoly Use of forward and spot markets				
	Forward 1	Forward 2	Spot	Total
Theoretical quantity ex-ante	28.57	28.57	28.57	85.71
Theoretical quantity in the residual demand (given past observed quantity)	28.57	25.73	28	-
Observed quantity	**35.68**	**22.3**	**27.58**	**85.56**
p-value (observation = theory) (*t*-test)	0 (8.05)	0 (11.0)	0.07 (1.47)	0.38 (0.29)
p-value (observation = theory in residual demand) (*t*-test)	0 (8.05)	0 (6.0)	0.268 (0.617)	-

As a benchmark it is useful to see what would happen if firms behaved competitively or as a monopolist. If firms behaved as a monopolist in the residual demand of the spot market then the quantity would be (½)(100-35.68-22.3) = 21.01. However, if firms behaved competitively in the residual demand of the spot market, then the market quantity would be 42.02 (relative to the observed quantity of 27.58). We cannot reject the hypothesis that spot and total quantities are the ones dictated by the theory. The fit is better if we make the comparison with the theoretical outcomes in the residual demand given the observed quantities.

Figure 1 below sheds some light on choices made by the subjects. Quantities shown are the average individual quantities for each round. We observe a decreasing trend in the quantities as periods advance. To capture this tendency, we present an analysis of the data for the first and last ten rounds in Table 5. The significant change between the first and the last 10 rounds is due to a shift from the forward to the spot market. That is, in later rounds subjects tend to sell less in the forward market and more in the spot, thus resulting in smaller sales.

We can have a clearer view of how subjects restrain output in a particular market if we analyze sales with respect to the equilibrium in the residual demand. In Table 5, what looks like a moderate 8.2% decrease (Observed First 10 vs. Observed Last 10) of sales in Forward 2 (the second period of forward markets), is now seen as a 21.2% decrease. This is due to the fact that, given the quantity in Forward 1, more should have been sold in Forward 2 in the last ten rounds. Conversely, what looks like a strong increase in the spot market (52%) is, in fact, a moderate one (9.1%) if, instead of comparing absolute quantities, we compare the percentage of the equilibrium quantities that these quantities represent. Note that all changes are statistically significant except for the change in the spot market measured as a percentage of the theoretical quantity in the residual demand (RD).

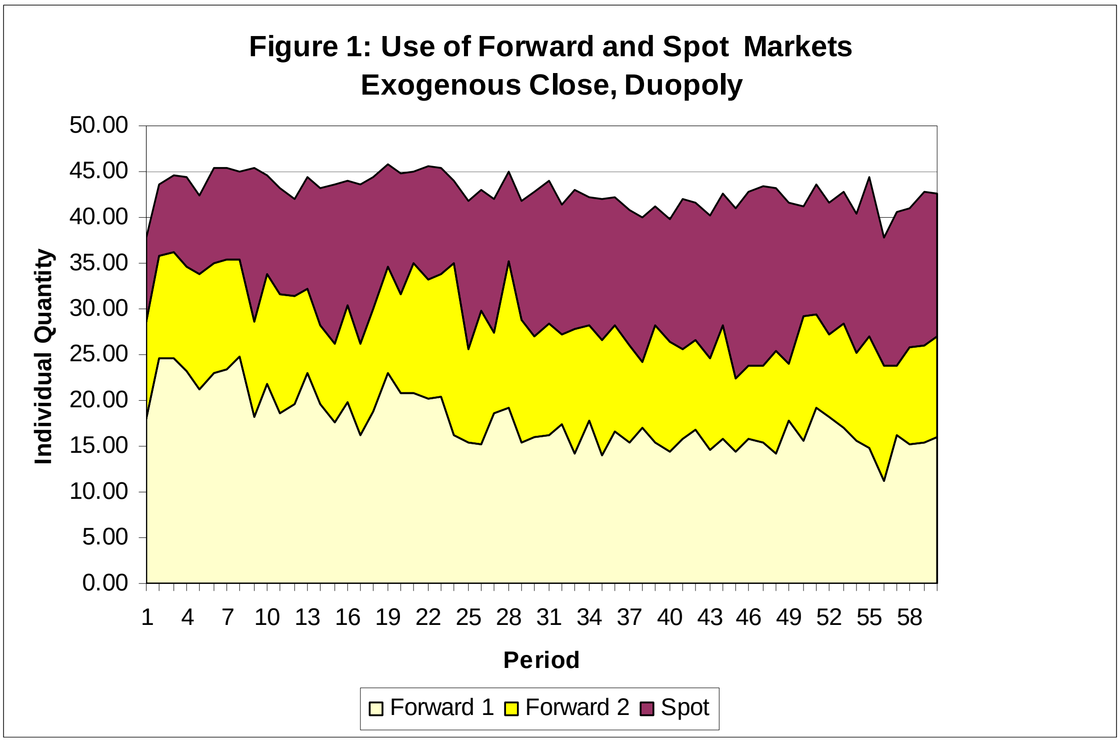


Figure 1: Use of Forward and Spot Markets Exogenous Close, Duopoly

Table 5: Exogenous Close, Duopoly
Use of forward and spot markets. First and Last ten rounds

		Forward 1	Forward 2	Spot	Total
Theoretical quantity ex-ante		28.57	28.57	28.57	85.71
First 10	Theoretical quantity in RD (given observed quantity)	28.57	22.18	21.73	-
	Observed First 10 (as proportion of theory in RD)	**44.54 (156)**	**22.86 (113)**	**20.26 (93)**	**87.64 -**
Last 10	Theoretical quantity (given observed quantity): RD	28.57	27.31	31.53	-
	Observed Last 10 (as proportion of theory in RD)	**31.72 (111)**	**20.98 (89)**	**30.80 (101.82)**	**83.5 -**
% Change of observation (*p*-value)		-28.8 (0)	-8.2 (0)	52 (0)	-4.7 (0)
% Change of observation when measured as a proportion of theory in RD (*p*-value)		-28.8 (0)	-21.2 (0.001)	9.1 (0.09)	-

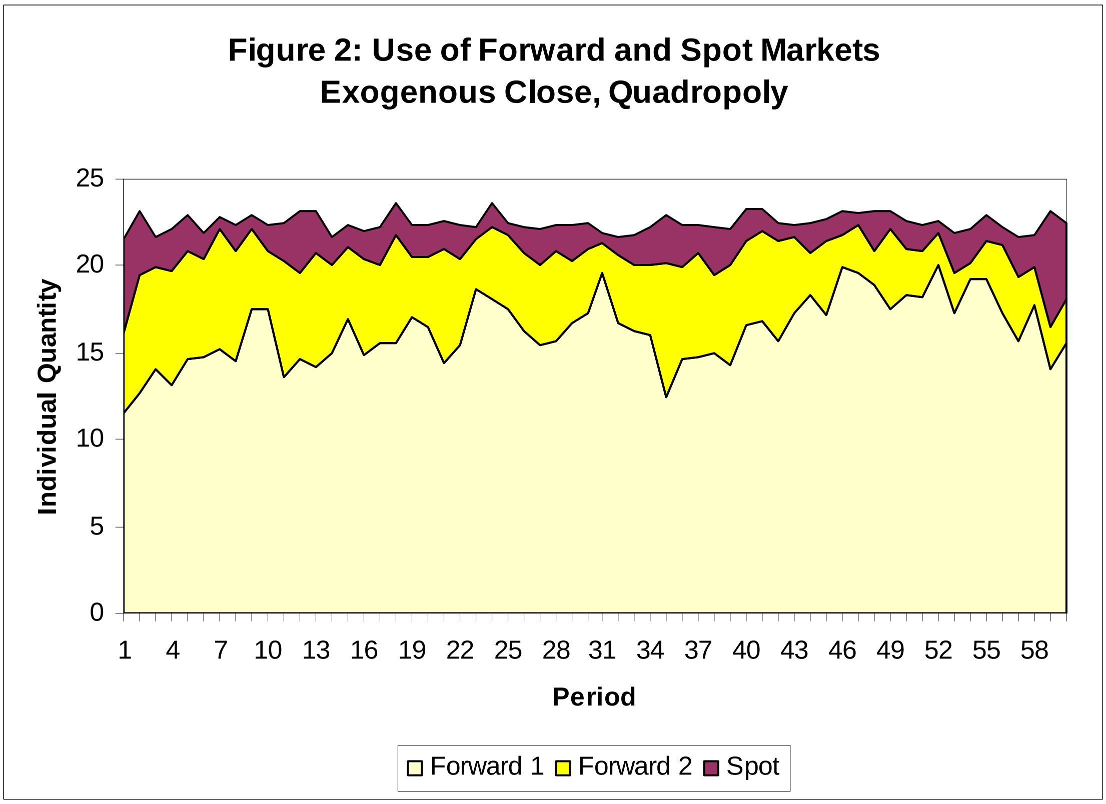
5.2 Exogenous Close: Quadropoly

Subjects behave remarkably close to the theoretical prediction in both the forward and spot markets under a quadropoly. The exact theoretical prediction is, however, rejected. When one contrasts the outcomes with respect to the theoretical prediction in the residual demand, then the behavior in the second period of forward markets (Forward 2) is as predicted by theory. Both spot and total quantities are not significantly different from competitive behavior. Our results are along the lines of Le Coq and Orzen where four or more agents behave more competitively than predicted by theory. Table 6 below shows this result.

Table 6: Exogenous Close, Quadropoly Use of forward and spot markets				
	Forward 1	Forward 2	Spot	Total
Theoretical quantity ex-ante	67.92	22.64	7.55	98.11
Theoretical quantity in the residual demand (given past observed quantity)	67.92	19.6	6.82	-
Observed quantity	**72.23**	**19.24**	**8.38**	**99.85**
Perfect competition in the residual demand	-	-	8.53	100
p-value (observation = theory) (*t*-test)	0.00029 (3.45)	0 (5.65)	0.015 (2.18)	0 (6.26)
p-value (observation = theory in residual demand) (*t*-test)	0.00029 (3.45)	0.27 (0.6)	0 (4.1)	-
p-value (observation = perfect competition) (*t*-test)	-	-	0.34 (0.39)	0.3 (0.53)

Again, as a benchmark, we calculate the monopoly and competitive outputs in the residual demand. These are, 43.65 ($=\frac{1}{2}(100-2.36-9.36)$) and 87.3, respectively. Also, recall that the Cournot quantity with one forward markets is 80. We do not show statistical tests as quantities are far from any reference values, and thus significantly different from them by any measure.

Figure 2 shows us the output choices made by subjects for quadropolies. Quantities shown are the individual averages for each round. The change in the spot market output is not statistically significant (see Table 7). There is an increase in the use of Forward 1 but a decrease in the use of Forward 2. Spot quantity is slightly above the theoretical prediction in absolute terms and a little lower in relative terms. Regardless, neither of these changes is statistically significant. The changes in the forward and spot markets, however, compensate each other so that there is no effect in the total quantity



.It may look paradoxical that observations are greater on average than the average theoretical prediction and that, at the same time, they are lower as a proportion of the theoretical prediction. The reason is that lower quantities also represent a lower proportion. For example, suppose that we have 3 observations in the spot market of 10, 2 and 18 after forward quantities of 90, 95 and 80, respectively, have been observed. The theoretical prediction in this case is $\frac{4}{5}(100 - \textit{forward quantities})$, which gives us 8, 4 and 16, respectively. The average of the three spot market observations is 10, greater than the average spot market theoretical prediction, which is 9.33. As a proportion of theoretical values, observations are 125, 50 and 112% of these quantities, giving an average of 95.66%.

Table 7: Quadropoly Exogenous Close Use of forward and spot-First and Last ten rounds					
		Forward 1	Forward 2	Spot	Total
Theoretical quantity ex-ante		67.92	22.64	7.55	98.11
First 10	Theoretical quantity in RD (given observed quantity)	67.92	24.86	8.09	-
	Observed First 10 (as proportion of theory in RD)	**64.78 (95.4)**	**25.11 (90.27)**	**9.5 (83.94)**	**99.39 -**
Last 10	Theoretical quantity (given observed quantity): RD	67.92	15.94	9.24	-
	Observed Last 10 (as proportion of theory in RD)	**77.42 (114)**	**11.03 (58.8)**	**10.64 (86.31)**	**99.09 -**
% Change of observation (*p*-value)		19.7 (0.001)	-56 (0)	12 (0.25)	-0.3 (0.47)
% Change of observation when measured as a proportion of theory in RD (*p*-value)		19.7 (0.001)	-34.8 (0)	-2.8 (0.48)	-

5.3 Endogenous close: Duopoly

Recall that in the endogenous close case the market moves over to the spot phase when no seller offers to sell anything in a forward market. To achieve this requires a certain amount of coordination, or tacit behavior, on the part of the subjects. We find that subjects found it hard to achieve this under the endogenous close rule. The endogenous close rule captures the prisoners' dilemma nature of the strategic motive to sell forward as subjects observe rival choices (individual for duopoly and aggregate for quadropoly) and can react to them in the next forward period. It is with this idea in mind that we designed the experiment to test the hypothesis whether subjects are able to coordinate and not use the future market. This would imply that all the sales take place in the spot market, where they would behave as a Cournot oligopoly.

We observe that the findings are completely at odds with this hypothesis, both market structures, duopoly and quadropoly behave competitively. Unlike the exogenous stopping rule, and also contrary to what has been observed in other oligopoly experiments, duopolists behave very competitively. A quantity very close to the competitive quantity is sold. Further, sales are almost entirely in the forward markets and, within them, in the earlier periods, with more than half of the sales in the very first period (see Figure A1 and Table 8). Accordingly, prices go rapidly to almost the competitive price. In Figure 3 is it seen that the mark up (price minus marginal cost) is very small in the fourth opening of forward markets. As a reference, the Cournot mark-up is 30. As the residual demand is very small in the spot market it is hard to give any meaning to subject behavior there.

Table 8: Endogenous Close. Output Choice. Forward vs. Spot Markets				
	Observed Forward	**Observed Spot**	Cournot in RD	Monopoly in RD
Duopoly	**98.7**	**0.1**	0.87	0.65
Quadropoly	**103.22**	**0.12**	0	0

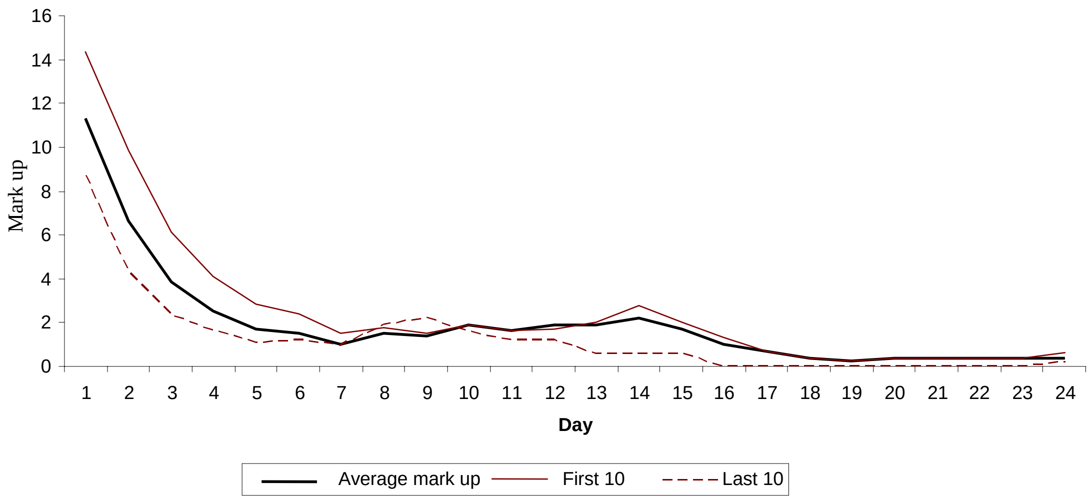
We observe three related trends as the experiment progresses. One is that the average number of forward markets that are open decreases from around 10 in the first rounds to half of that in the end (see Figure A.2). This has no major consequences on total quantities as sales after fourth forward market are very small in any case. The second is that, as the experiment progresses, sales accumulate more in the two earliest openings of the forward market, from 56.77% in the first 10 periods to 79.28% in the last ten. The third is that the mark-up goes down from 14.3, 9.9, 6.1, and 4.1 in the first four openings of the forward markets in the first 10 rounds of the experiment to 8.7, 4.3, 2.3, and 1.6 in the last ten, as seen in Figure 3.

The evolution of prices is of particular import to our hypothesis. Recall that the hypothesis of collusive behaviour implies no use of forward market and Cournot behavior in the spot market. Any small quantity sold in a forward market would be traded at almost the Cournot price, as the price in forward markets are computed as the Cournot price in the residual demand. We do not find this, and, thus, the hypothesis is rejected.

However, the alternative hypothesis that players behave competitively implies that the price in all forward markets must be competitive, and the corresponding mark-up, zero. This is neither accepted nor rejected, as the experiment does not set this price. However, even if the experimental price is set equal to the Cournot price in the residual demand, the fact that large quantities are sold in the early openings of forward markets makes a smaller residual demand as markets open, with a price that indeed approaches to the competitive price. This is even more so in the last round of the experiment.

In other words, the Cournot price in the residual demand converges to the competitive price. In this sense the experimental behavior converges to the competitive hypothesis.

Figure 3: Price per market opening
Endogenous close, Duopoly



5.3 Endogenous close: Quadropoly

In the quadropoly case, the average quantity produced in the forward stage is 103.22 and is almost the same as the competitive 100 (table 8). The *p*-value obtained from the *t*-test is 0.032. As in the case of the duopoly, sales take place almost entirely in the forward markets. The only difference is that the concentration in the first period is even grater (Figure A4). No residual demand is left after the use of the forward markets. As a result there is nothing interesting to be seen in the spot market.

Behavior for subjects does not change much as the rounds unfold. The average quantity chosen in the forward markets is 98.45 and 98.7 for the first and last ten rounds, respectively. The spot quantities are 0.14 and 0.06. None of the differences is significant (with *p*-values of 0.46 and 0.13, respectively).

The mark-up (price minus marginal cost) at which forward positions were sold averages 3.48 in the first opening of forward markets and 0.11 in the second. The mark-ups in the other forward periods and in the spot market are almost identical to zero (see Figure A3). Recall that these mark-ups are computed by exogenously using the Cournot price in the residual demand. By comparison, the mark-up if the forward market were never use is 20 and the competitive mark-up, zero. Although statistically different in the earliest periods, the realized prices come remarkably close to the competitive level even if we computed them under the "collusive" hypothesis. I.e., the same, although stronger, convergence to competitive behavior that we observed in the duopoly is observed here.

Forward markets were open an average of 4-5 times in the earlier periods, and showed a small decline as periods pass by (Figure A5).

5.5 Increasing the number of firms vs. opening forward markets

In another paper (Ferreira *et al.*, 2010) we report some experimental Cournot regarding Cournot oligopolies with experienced subjects[10]. Below we compare some results from this paper with the exogenous and endogenous close forward markets experiments. By doing so, we compare the effect of introducing more firms in the market, *i.e.*, 2 vs. 4, and the addition of forward markets. Table 9 summarizes average sales by duopolies and quadropolies (with no forward markets) against the exogenous close and the endogenous close forward markets.

Table 9: Cournot vs. Forward

	Cournot without experience	Cournot with experience	Cournot with Forward markets. Exogenous Close	Cournot with Forward markets. Endogenous Close
Duopoly	70	53	85.56	98.32
Quadropoly	84.58	81.58	99.85	103.23

This comparison shows that the effect of introducing two periods of forward market in a duopoly is similar to the effect of increasing the number of firms to four. Le Coq and Orzen showed that when the number of futures markets is one, the effect of increasing the number of firms in competition is higher.

However, the smaller quantities produced by the experienced subjects opens the question whether this effect would also be the same if the Allaz and Vila game is also played with experienced subjects. The more complicated structure of the forward markets game may make it more difficult for players to coordinate quantity reduction.

One may be tempted to assert that the introduction of forward markets with the endogenous close rule imposed in the experiment may be one of the keys to competition (Table 9). This is not necessarily the case. Recall that the experiment was designed to test whether subjects behave like a Cournot oligopoly, and accordingly, the forward price was set equal to the Cournot price in the residual demand. As the experimental observation reject the hypothesis, the forward price does not correspond to subjects

[10] The experiments were also performed at George Mason and Chapman, and thus can be used to make a proper comparison.

behavior. New experiments in which the forward price is endogenously determined are necessary to shed more light into this issue.

6. Conclusion

There is some controversy about the effect of the introduction of forward markets on market competitiveness. They are widely used and little understood. Depending upon the model, theory provides results suited to all tastes. The introduction of forward markets can have pro- and anti-competitive effects. The experimental literature is still scant, but seems to favor the competitiveness of forward markets. Le Coq and Orzen (2006) provide some support for theory for a duopoly and stronger support for a quadropoly. Brandts et al. (2008), meanwhile, show that the introduction of forward markets can result in competitive outcomes.

We design our experiments to test the theory as presented in Allaz and Vila. Our design differs from Le Coq and Orzen in many important ways. First, we randomly match firms vs. the fixed matching rule adopted in Le Coq and Orzen. Our structure is the true test of the one shot prediction in Allaz and Vila. Second, we run our experiments for a longer duration. Past experiments in quantity setting oligopolies have shown that behaviour in the second half of longer experiments is quite different from behaviour in the first part. Our experiments also corroborate these results. Third, we run a higher number of periods of forward markets.

Compared with Le Coq and Orzen, we find stronger support for the theory. Average output in our experiments is remarkably close to the theoretical prediction in both the final total quantity and the use of forward markets. Output produced by our subjects does capture the prisoners' dilemma nature of the strategic motive to sell forward. Further, behavior in the forward and spot phase in our experiments corresponds more to the theoretical prediction. This is especially the case under duopolies.

The experimental results suggest a number of questions. First, in view of the effects of experience in Cournot markets, it seems only reasonable to conduct the experiment with experienced subjects. Second, the experimental design relies in the imputation of a price to quantities sold in the forward market. This is done by using the theoretical predictions. A more complete design that allows the endogenous determination of this price will solve this problem. Third, the introduction of arbitrageurs that can freely buy and sell in the markets would add a more realistic feature to the experiment. We are working on these issues currently.

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APPENDIX 1

Figures

Figure A1: Use of Forward and Spot Markets
Endogenous close, Duopoly

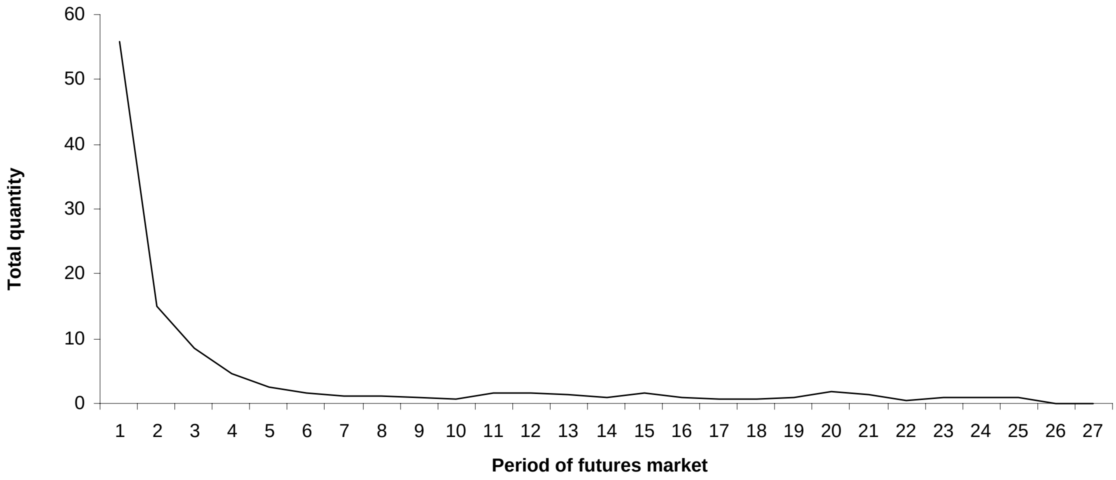


Figure A2: Number of forward markets
Endogenous close, Duopoly

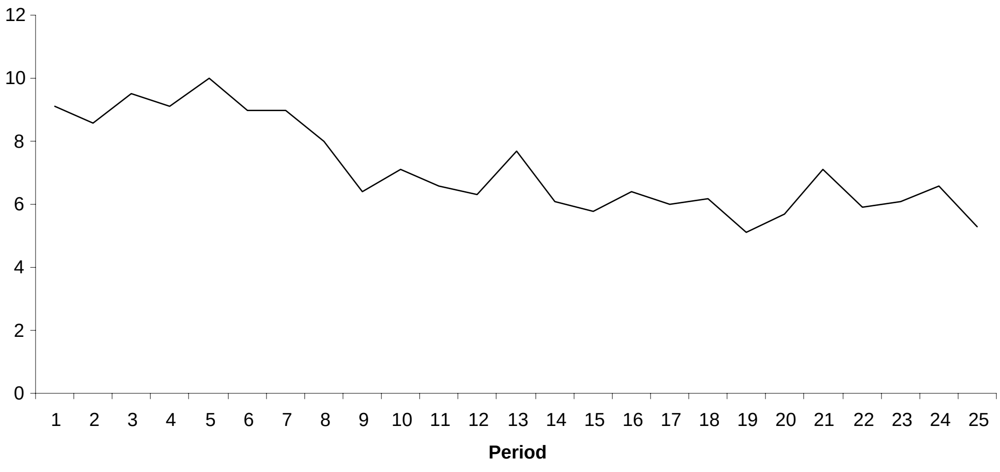


Figure A3: Price per market opening
Endogenous close, Quadropoly

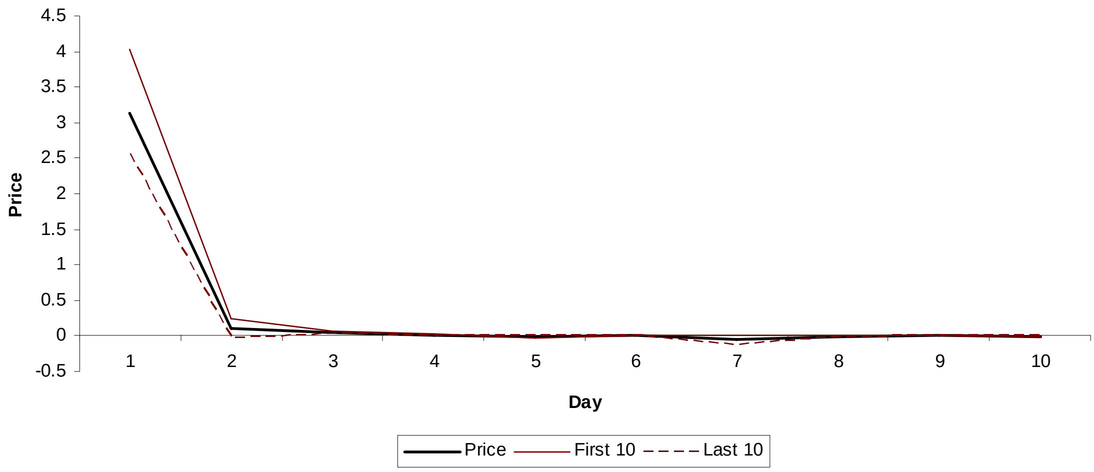


Figure A4: Use of Forward and Spot Markets
Endogenous Close, Quadropoly

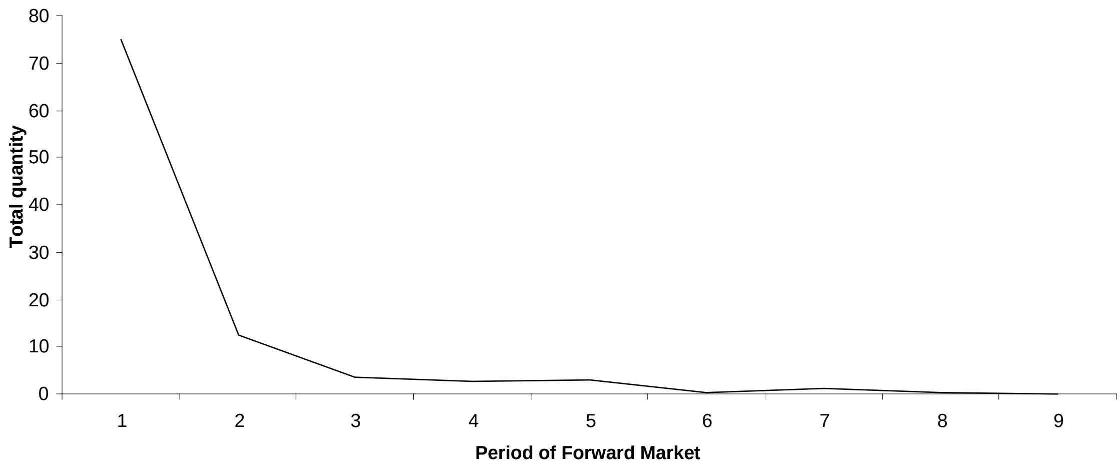
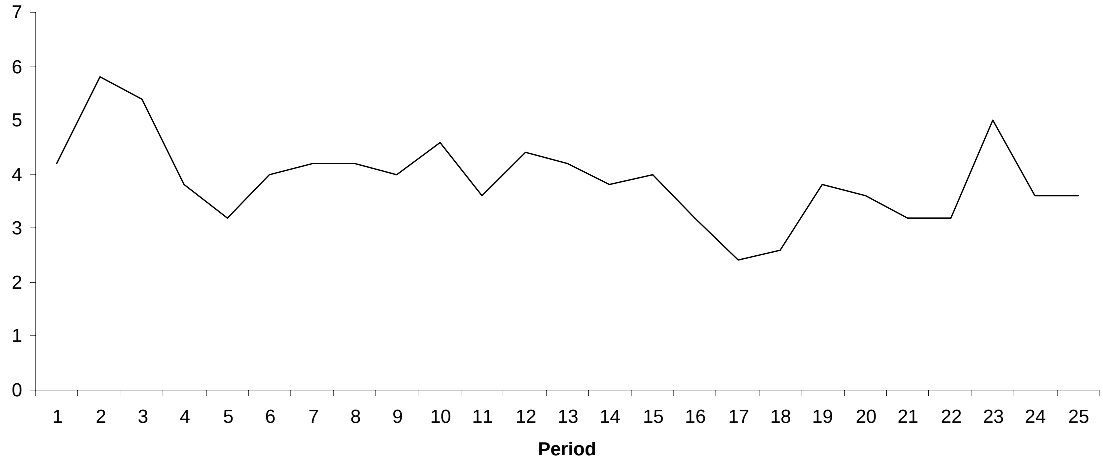


Figure A5: Number of Forward Markets
Quadopoly Endogenous Close



APPENDIX 2

Instructions for in-experienced subjects.

INSTRUCTIONS

Introduction: This is a study of decision-making. Funding for this project has been provided by public funding agencies. If you follow these instructions, and make decisions carefully, you might earn a considerable amount of money. You will be paid **IN CASH** at the end of today's session.

Important: At any stage you can raise your hand to ask any question relating to the experiment.

Overview: In today's session each of you is a quantity-setting seller. There are TWO sellers in each market. The experiment is made up of several **weeks.** Each **week** is made up of three **trading days**. You will be randomly and anonymously matched against other opponents.

Trading in each week proceeds as follows:

Each week is made up of **three days**. Note that, the total of the offers made in all the days constitute a **commitment** to sell a good and are final. **In each day you make profits for the quantities sold in that day only**.

First Day:

In the first day you will have 30 seconds to make quantity offers. Note that, once confirmed all **offers to sell** are FINAL and cannot be changed. At the end of the day you will be able to see the quantities offered by the other seller, the price, and your profits **for the day**.

Second Day:

You may choose, or not, to **increase** upon the offer you made in the first day. You will have 30 seconds to make quantity offers. Any change can only be an increase over the total quantity offered in day-1. At the end of the day you will be able to see the quantities offered by the other seller, the price, and your profits **for the day (only for the additional quantity sold in this day)**.

Final Day:

This is the final day of the week. You may choose, or not, to increase the offer you made in the first two days. Any change can only be an increase over the total quantity offered in days -1 and -2. At the end of the day you will be able to see the quantities offered by the other seller, the price, and your profits **for the day (only for the additional quantity sold in this day)**.

You can offer to sell quantity in all, or any, of the days. The **price** received by sellers is the **same for everyone.**

- The market price in Day 1 is determined by the sum total of quantity offered by ALL sellers during that day and a **computer estimate of the quantity that will be sold on Day 2 and the Final Day**.
- The market price in Day 2 is determined by the sum total of quantity offered by ALL sellers during Days 1 and 2 **and a computer estimate of the quantities for the Final Day**.

Example 1 below explains how the price is determined in **the Final day**.

<u>Example 1</u>: Let the market demand be P=10-TQ (P = market price, TQ = total quantity offered by all sellers). Suppose you offered to sell **ZERO units** on **day-1, ONE additional unit** on **day-2, and ONE on Final day**. The sum total of the units offered by you then is 2 (=1+1).

Let us also suppose that the number of units offered by the other seller on **day 1** is 1**,** 1 on **day 2, and ZERO on the Final Day**. The total quantity (TQ) offered by all sellers across the week then is (3+2=) 5. This implies that the market price for the Final Day is P = 10-TQ = 10-5 = **5**.

Note that the price declines as the total quantity offered (TQ) increases. For all TQ greater than, or equal to, 10 the market price (P=10-TQ=10-10=0) is zero. **Further note that, the market price can never be negative.**

Example 2 below explains the relationship between the total quantity offered (TQ) and the market price in the Final Day (P).
<u>Example 2:</u> Notice that the market price (P=10-TQ) decreases as the total quantity (TQ) sold in the market increases. The table below gives some possible prices for the Final Day for different total quantities (TQ):

Market demand: P=10-TQ	
QUANTITY (TQ)	PRICE (P)
1	P = 10-1 = **9**
2	P = 10-2 = **8**
4	P = 10-4 = **6**
6	P = 10-6 = **4**
7	P = 10-7 = **3**
8	P = 10-8 = **2**
9	P = 10-9 = **1**
10	P = 10-10 = **0**

Procedures for trading are explained in more detail below.

1. Sellers earn profits by selling units. The profit for any unit sold is the selling price minus the cost of the unit. The selling price will be the same for all units, as will be unit costs. Thus a seller's total profit is;

Profits in the Final Day = (Selling Price – Unit Cost) × Number of units sold in the Final Day

2. Buyers. The buyers are automated. The price is determined according to the demand in **Example-1**. Given total quantity (TQ), the market price P=10-TQ. In our example TQ=5, this implies that P = 10-TQ = 10-5 = 5.

Note that the same demand will not be used in the experiment.

In Days 1 and 2, the price is computed by the computer. As explained before the **computer estimates the quantity that will be sold on Day 2 and the Final Day**.

Before you confirm your quantity for the day, you can practice with different quantities for yourself and for the other seller (to have an estimate of the effects on your profits of the total quantity offered that day).

There are several important things to understand.

- The higher (lower) is the total quantity (TQ), the lower (higher) is the price (P) (see **<u>TABLE</u>** in **Example 2** above).
- Your sales are affected by the quantities chosen by the other seller. The higher (lower) is the other seller's quantity lower (higher) is the sales price. The same will be true if you increase your quantity and the other seller does not.

- **A higher quantity today may increase your profits today but may decrease profits later on in the week.**

<u>The trading week:</u>

Each seller can offer to sell some quantity (or none) in each day of the week. While choosing the quantity you should keep in mind that,

(i) you earn profits by selling units at a price above Unit Cost and
(ii) the higher is total quantity, the lower is the sales price (see **table** above).
(iii) you earn zero if you sell nothing.

<u>How to read the screen and submit your offer?</u>

On the right side of the screen, there is a **history table**. A record of all the plays is displayed in the table.

On the left side of the screen, there is a **graphical display** section.

You can try different possible combinations of your offer, the sum of all the other sellers offers and observe your potential profit **on the right side of the display section**.

After you have decided your offer for that day, click the CONFIRM button. NOTE that whenever you click the CONFIRM button, you are confirming **your offer only**. The actual number of units offered by other sellers may be different from yours. Also, NOTE that you **must** click the CONFIRM button in order to submit your offer.

The left side of the graphic display section shows your quantity, the sum of other sellers' quantity and the profit given the price on a particular day.

4) Overview:

a) Today's experiment will consist of a number of **weeks**. A trading week is made up of **three days**. The final trading week will not be disclosed in advance.

b) Each of you can choose to offer a quantity for sale in any trading day. You will be randomly and anonymously matched against other opponents.

c) In today's experiment each one of you will have a Unit Cost of $X in each period. Each participant has identical Unit Costs, and Unit Costs are the same in all trading weeks. You are also informed about the other seller's Unit Costs in a history table on the Right Side of the screen.

d) You will be paid $X U.S. for every Y "experimental dollars" you earn in the market. Thus, for example, every Y experimental dollars equals $U.S. Your total earnings for today's session will be the sum of your earnings in the experiment, plus your appearance fee.

e) Some participants may make their quantity decisions earlier than others. If you make your decision before other sellers, please wait quietly while others finish. The monitor will make sure that there are no unnecessary delays.

f) Please note that, talking with, or looking at, other participants is not allowed. The market will be closed and all participants will be dismissed without further payment if any participant communicates in any way other than the manner described in these instructions.

g) At the end of the experiment you will be called out and your earning will be paid to you in cash.

You will now practice before you start the experiment. Please free feel to continue the practice until you are ready for the experiment. Please click on “Ready to Practice” if you fully understand the instruction.